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ASPECTS OF INFORMATION FEEDBACK AND PARAMETER UPDATE DESIGN FOR A SEISMIC SURVEILLANCE SYSTEM

Rudolf Unger, et al

Texas Instruments, Incorporated

Prepared for:

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31 December 1974

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ASPECTS OF INFORMATION FEEDBACK AND PARAMETER UPDATE DESIGN FOR A SEISMIC SURVEILLANCE SYSTEM

TECHNICAL REPORT NO. 14

VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

Prepared by
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TEXAS INSTRUMENTS INCORPORATED
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Alexandria, Virginia 22314

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An information feedback and parameter update design study is presented as an extension of an earlier study of a seismic surveillance system. Based on system concepts developed in the previous study, this report gives an overview of system interactions, and discusses the problems related to detection threshold control and the computation and application of beamforming and event classification parameter corrections.

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ABSTRACT

An information feedback and parameter update design study is presented as an extension of an earlier study of a seismic surveillance system. Based on system concepts developed in the previous study, this report gives an overview of system interactions, and discusses the problems related to detection threshold control and the computation and application of beamforming and event classification parameter corrections.

TABLE OF CONTENTS

SECTION	TITLE	PAGE
	ACKNOWLEDGMENT	iii
	ABSTRACT	iv
I.	INTRODUCTION	I-1
II.	SYSTEM AND INTERACTIONS	II-1
	A. SYSTEM SUMMARY	II-2
	B. SYSTEM FILES AND INTERFACE	II-4
	C. PARAMETER INTERACTION	II-14
	D. STORAGE AND COMMUNICATIONS REQUIREMENTS	II-17
III.	PARAMETER UPDATE TECHNIQUES	III-1
	A. REGIONAL CORRECTIONS	III-1
	B. THRESHOLD CONTROL	III-6
IV.	SUMMARY AND CONCLUSIONS	IV-1
V.	REFERENCES	V-1

LIST OF FIGURES

FIGURE	TITLE	PAGE
II-1	BASIC SYSTEM BLOCK DIAGRAM	II-3
II-2	REMOTE FACILITY FILE AND INTERFACE SYSTEM	II-5
II-3	CENTRAL FACILITY FILE AND INTERFACE SYSTEM	II-6
II-4	PARAMETER INTERACTION DIAGRAM	II-15
III-1	DECISION ERROR CONSEQUENCES	III-9
III-2	DETECTION THRESHOLD SETTING	III-14
III-3	MINIMUM-COST THRESHOLD SETTING FOR A LINEAR DETECTOR	III-20
III-4	MISSED-DETECTION-OVER-FALSE-ALARM COST RATIO AS A FUNCTION OF TARGET MAGNITUDE FOR A GIVEN LIKELIHOOD OF DETECTION (FOR AVERAGE SEISMICITY BEAMS)	III-24
III-5	MINIMUM-COST THRESHOLD VERSUS TARGET MAGNITUDE EVENT SIGNAL DETECTOR OUTPUT FOR A GIVEN LIKELIHOOD OF DETECTION	III-25
III-6	TYPICAL CURVE OF COST MINIMA AS A FUNCTION OF K AND μ_S FOR STRATEGY OF MINIMUM THRESHOLD FOR A GIVEN K	III-28

LIST OF TABLES

TABLE	TITLE	PAGE
III-1	INTERDEPENDENCE OF CRITICAL THRESHOLD CONTROL PARAMETERS	III-23

SECTION I
INTRODUCTION

In Special Report No. 17 (Sax et al., 1974) the results of a preliminary study on a world-wide seismic surveillance network were presented. That work contains the basic system concepts, the trade-offs between centralized and decentralized systems, the approaches to several basic problems, and estimates of required processing and communications needs. An optimum seismic surveillance system must continuously adapt to changes in its external and internal conditions (e.g., a storm increasing a station's noise level and thereby lowering its detection capability; earthquake swarms causing an increase in data transmission and processing; sensor breakdown). This requires feedback of information from the ultimate information collection and system control points to the lower processing levels, and the updating of signal processing parameters and algorithms. This report discusses the problems anticipated in the design of such a feedback and parameter update technique.

For instance, one of the basic feedback problems is the setting of the station detection thresholds. These determine directly the false alarm and missed detection rates, the system processing and communications loads, and the station and network detection capabilities.

In updating parameters, one is concerned with the fact that wave propagation does not necessarily take place along the great circle path between event source and station. Also, wavefronts may not be planar when propagating over an array. The first fact causes anomalies in beam direction, inverse velocity, travel time, sensor delay times, magnitude and spectral contents for each region-station path. The second fact causes additional (usually random) sensor delay time anomalies. For certain station-region relationships, these anomalies are expected to show consistent bias. The system then may be designed to be adaptive so that it can generate corrections to these anomalies to enhance the accuracy and quality of event indicators and estimators utilizing array measurements.

Finally, the system control center needs to be continuously updated on processing and communications loads at the various levels to maintain efficient system performance.

The framework for the discussion of the above mentioned and related topics is developed in Section II. It presents a brief summary of the system concept adopted in the preliminary study, followed by a discussion of the file and interface system, in which certain feedback and parameter update concepts have been incorporated. Based on this information the system interactions are then sketched. The section concludes with an estimation of storage and communications requirements for information feedback and parameter updating. Section III specifically studies the parameter update and threshold control design problems. The report concludes with the summary and conclusions in Section IV, and a list of references in Section V.

The concepts presented in this analysis are only a choice from several possibilities of approach, and are not necessarily the best. However, they serve the purpose of defining and describing general problem areas inherent in seismic surveillance system feedback and parameter update design. The optimal approach can only be found from more detailed analysis and in particular from system simulation after the overall surveillance system configuration is selected.

SECTION II

SYSTEM AND INTERACTIONS

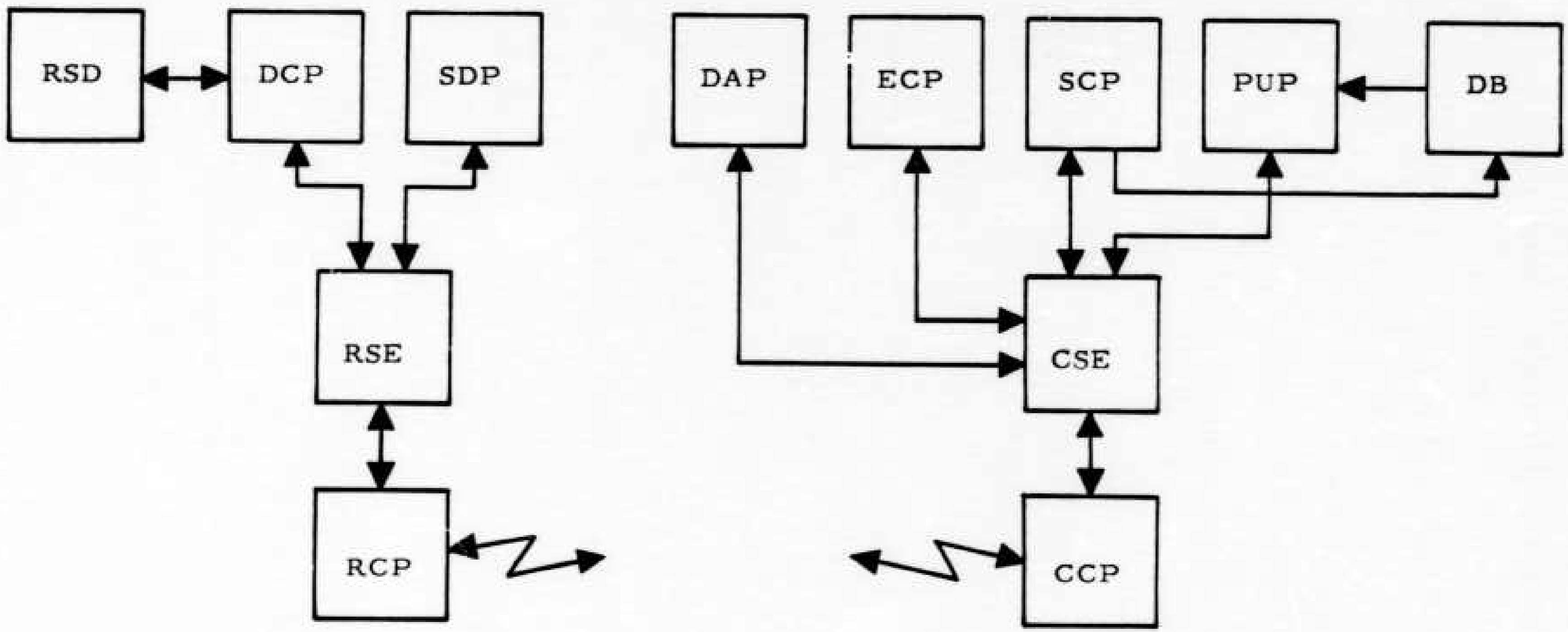
This part of the study summarizes the basic system and its method of operation, describes the file and interface system, analyzes the system interactions, and derives storage and communication requirements for information feedback and parameter updating. The analysis is based on concepts aaopted in Special Report No. 17 (Sax et al., 1974) concerning the seismic surveillance network study. In particular, the decentralized system with a network consisting of 25 medium size (10-12 km) arrays, each with 19 SP and 7 LP sensors, is considered here.

In the discussion below the analysts at the various processor levels are assumed part of the system. Thus, when it is stated, for instance, that overall system control is performed by the system control processor, this control is meant to be interactive, with the analyst at that level selectively making decisions. Similarly, providing algorithm updates by the parameter update processor means, of course, that the analysts at that level develop the algorithm and test it at that processor. Furthermore, although in the discussion and in the block diagrams the various processor functions have been separated, some processors may well be combined in the ultimate system design if workload or organization efficiency would suggest so. Finally, in the system model described below, the detection mechanism is based on beam envelope signal-to-noise ratio z-statistic detection. This method could be replaced, however, by other detector types (e.g., Fischer detector) without disturbing the general system concept.

A. SYSTEM SUMMARY

A block diagram of the basic system components is given in Figure II-1. At a station, or "remote facility," the sensor waveforms received by the remote sensor deployment (RSD) are collected by the data collection processor (DCP) and stored on the remote storage element (RSE). The RSE is shared by the DCP and the station detection processor (SDP). The SDP performs beam envelope signal detection. Upon detection a detection bulletin is issued containing signal arrival time, beam direction, inverse velocity ($dT/d\Delta$) and auxiliary parameters. Requested waveforms, noise parameters, detection bulletins, and other parameters and messages destined for central facility processing or storage are queued on the RSE for transmission to the central facility by the remote communications processor (RCP). Waveform requests and algorithm and parameter updates received from the central facility are queued on the RSE by the RCP for processing and use by DCP and SDP. The RSE furthermore holds the processing algorithm and correction parameters used in station processing. The DCP provides network time and synchronization for the RSD.

At the central facility, information received and to be transmitted by the central communications processor (CCP) is queued on the central storage element (CSE). The CSE is shared by all central facility processors. The detection association processor (DAP) tries to associate the detection data issued by the various stations to yield the event focal parameters, upon which it stores its association report on the CSE and requests the beamed waveforms for those focal parameters. The event classification processor (ECP) analyzes the beamed waveforms to obtain refined focal parameters and to further classify the event by region, source and earthquake/explosion discrimination. At completion of this classification process the ECP issues the event classification report, containing all relevant event and processing information, for storage, together with the event's beamed waveforms, in the data bank (DB) via the CSE. Regional and



Remote Facility

RSD = Remote Sensor Deployment
DCP = Data Collection Processor
SDP = Station Detection Processor
RSE = Remote Storage Element
RCP = Remote Communications Processor

Central Facility

DAP = Detection Association Processor
ECP = Event Classification Processor
SCP = System Control Processor
PUP = Parameter Update Processor
DB = Data Bank
CSE = Central Storage Element
CCP = Central Communications Processor

FIGURE II-1

BASIC SYSTEM BLOCK DIAGRAM

station parameter anomalies, and corrections for these anomalies are compiled by the parameter update processor (PUP) from data residing in the DB. The PUP furthermore can evaluate processor and system performance, and may perform research and development with these data; also, it may assist other processors with special problems.

The system is managed and controlled by the system control processor (SCP). It brings up the system, performs overall system quality control (beyond each processor's own data and subsystem quality controls) checks waveform requests, distributes algorithm and parameter updates compiled by the PUP, and, most importantly, controls the overall system surveillance performance by setting the network detection capability based on station signal-to-noise ratios and the "cost" of false alarms and missed detections.

The above is only a rough description of the network operation. In the following subsections, in the course of establishing feedback and parameter update techniques and procedures, the system functions, parameters and files are expanded and treated in more detail.

B. SYSTEM FILES AND INTERFACE

This subsection defines the parameters and algorithm files stored on RSE and CSE, and describes their interface with the various processors. Figure II-2 illustrates the file and interface system concept for the remote facility, the central facility file and interface system concept are shown in Figure II-3. In the remote facility as well as in the central facility the storage elements are also used as the interface between processors.

1. Remote Facility Files and Interface

The remote facility file and interface system is as follows:

- SP, LP sensor waveforms. These are the waveforms collected by the DCP from the RSD and deposited by the DCP on the RSE, where they are held for a period of time, for instance, six hours.

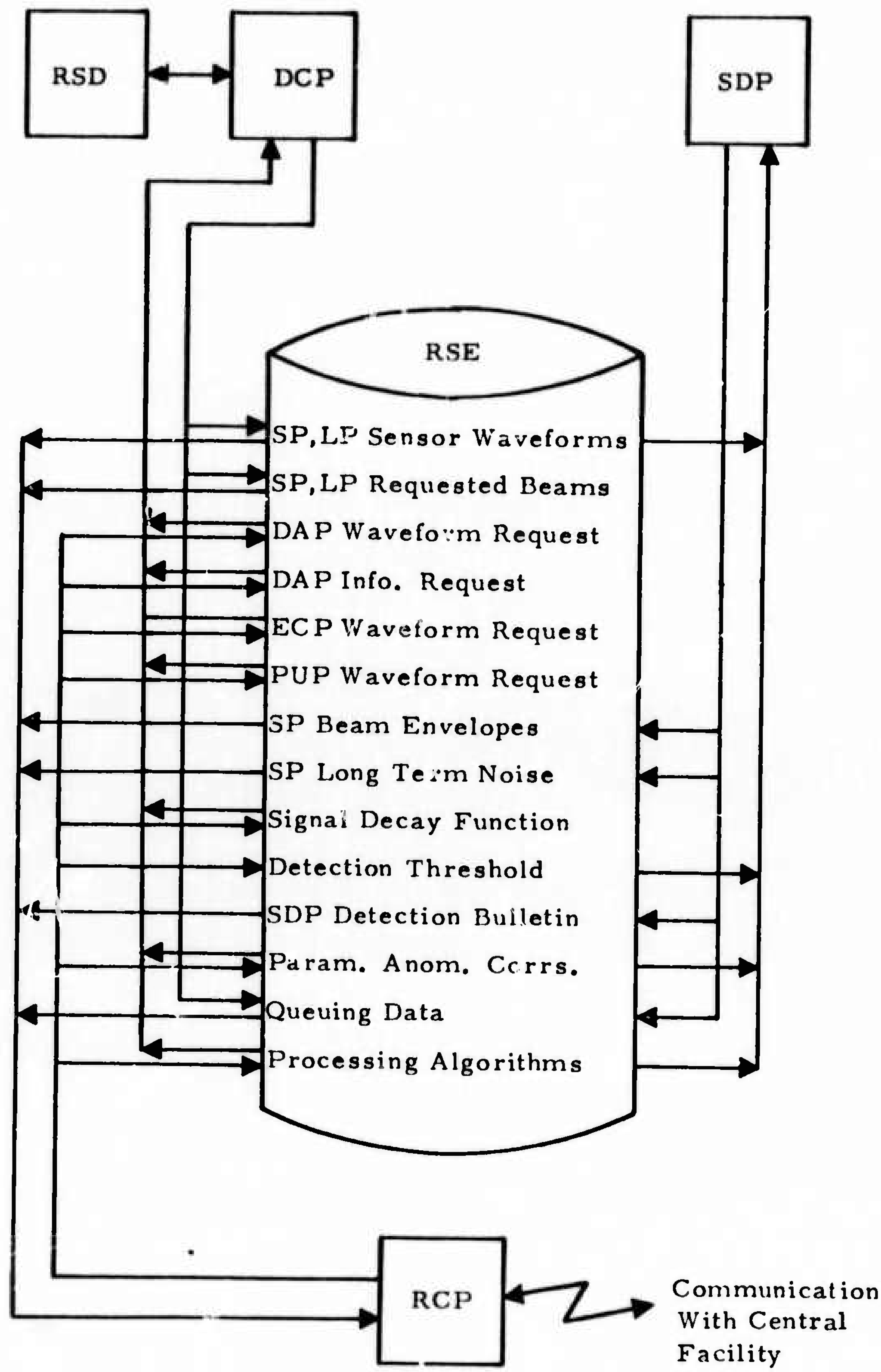


FIGURE II-2

REMOTE FACILITY FILE AND INTERFACE SYSTEM

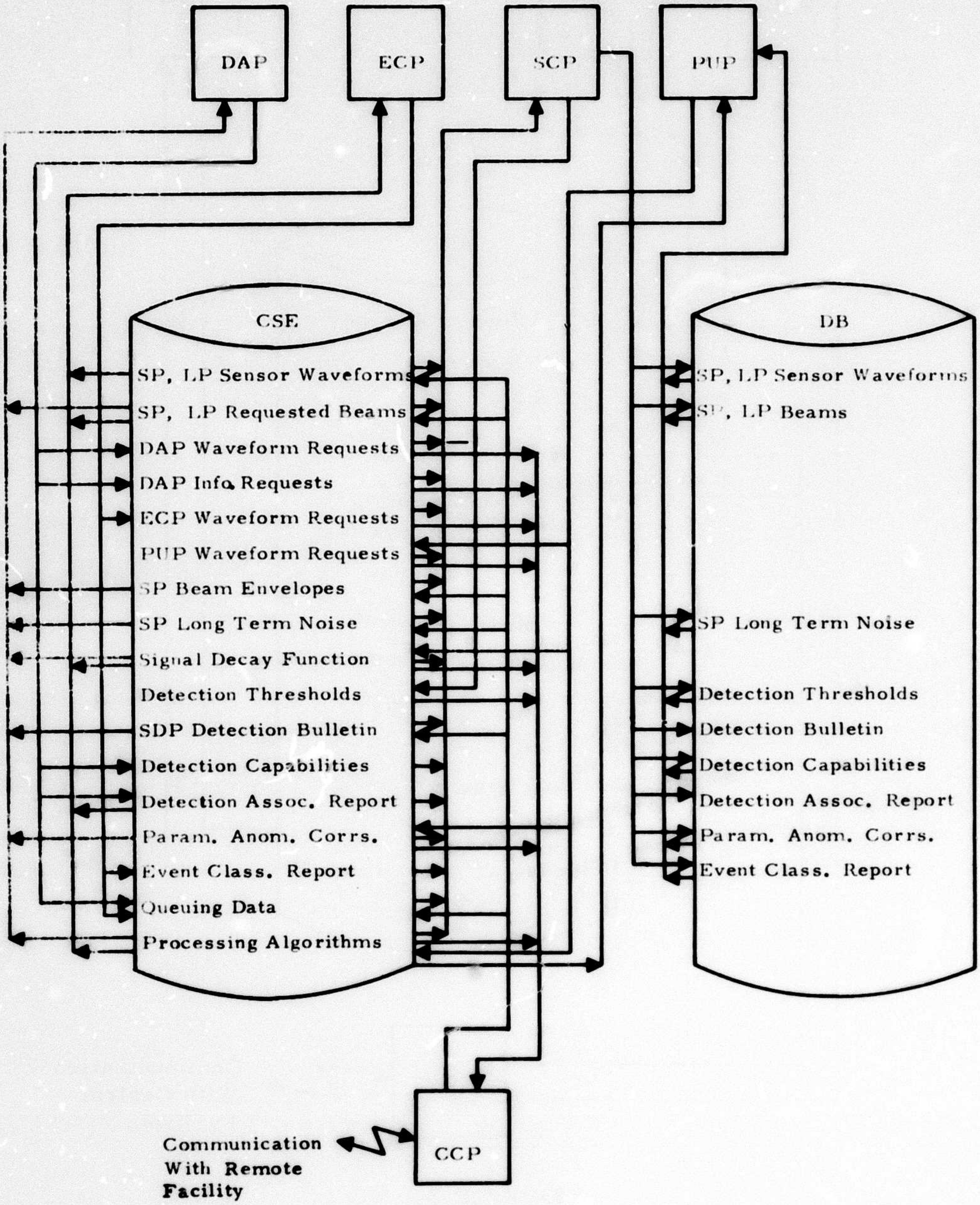


FIGURE II-3

CENTRAL FACILITY FILE AND INTERFACE SYSTEM

They are read immediately by the SDP for routine beam envelope processing, and by the RCP for transmission to the central facility to satisfy ECP, and, occasionally, PUP waveform requests.

- SP, LP requested beams. These waveforms have been beamformed and deposited by the DCP, for focal parameters specified by the DAP. Corrections for direction, $dT/d\Delta$, travel time and sensor delay time anomalies have been applied; the time window is determined from the signal decay function. This data block furthermore consists of the beam parameters and corrections used, and the request identification. It is read by the RCP for transmission to the central facility.

- DAP waveform requests. These requests are received by the RCP from the central facility, and deposited on the RSE. They consist of the DAP request identification and the focal parameters (origin time, latitude, longitude, depth, m_b) for which the waveforms are to be beamformed. The requests are read and processed by the DCP.

- DAP special information requests. These are received from the central facility by the RCP and deposited on the RSE. They may request extra information, such as beams in special or extended time windows, extended detection information, etc., to enhance the assocation process. They are read and processed by the DCP. Requests are coded to identify the type of information desired.

- ECP waveform requests. These are received from the central facility by the RCP and deposited on the RSE. Sensor waveforms and possibly extended time windows are requested for specified focal parameters. The DCP reads and processes the requests consisting of the request identification and the focal parameters of the event concerned.

- PUP waveform requests. These are not anticipated as routine but as experimental modes of waveform data collection which essentially follow the format of ECP waveform requests.

- SP beam envelopes. These initiate event detection. They are computed routinely by the SDP from the sensor waveforms provided by the DCP, for a fixed number (k) of beams sufficient to cover the wavenumber space within beam and velocity resolutions. Maximum envelope beams are optimized by "fine tuning", i.e., varying beams and inverse velocities slightly about the maximum envelope beam until the optimum wavenumber is found. If the maximum z-statistic of the log A/T value (A=maximum envelope, T=dominant period) in, for instance, a 15-sec time gate exceeds the detection threshold set by the central facility, a detection bulletin is sent to the central facility. If the maximum beam does not exceed the detection threshold the maximum log A/T values of each of the k beams update the long term noise mean and standard deviation (s.d.). The beam envelopes are deposited on the RSE for a limited period, for possible retrieval by the RCP to satisfy DAP special information requests. Also, special DAP requested beam envelopes can be generated by the DCP and stored on the RSE for transmission by the RCP.

- SP long term noise. The mean and s.d. of the maximum log A/T beam envelope values are updated by the SDP as described above, for the k beams, and stored on the RSE. The SDP keeps the most recent values in core to determine the z-statistic of maximum log A/T beam envelope values. The mean and s.d. are read by the RCP to be included in hourly messages transmitted to the central facility.

- Signal decay function. Updates for this function are received from the central facility and deposited on the RSE by the RCP. It is read and used by the DCP to determine region-magnitude dependent time windows of requested waveforms.

- Detection thresholds. These are set by the central facility and received by the RCP for deposit on the RSE. They are read by the SDP for signal detection decisions.

- SDP detection bulletins. These are issued when the maximum beam exceeds the detection threshold. They consist of arrival time, beam direction, $dT/d\Delta$, sensor delay times used, long term noise mean and s.d., maximum log A/T value, type of noise, other comment and station identification; plus the s.d. of these parameters where applicable. The detection bulletins are stored by the SDP on the RSE, and read by the RCP for high priority transmission to the central facility.

- Parameter anomaly corrections. These are deposited by the RCP upon reception from the central facility. They are read by the DCP and the SDP for use in beamforming and timing. The parameters concerned are:
  - Direction (deviation from the great circle path between event location and station)
  - $dT/d\Delta$
  - Travel time
  - Sensor delay times
  - Magnitudes.

- Queuing data. These describe the processing loads at the DCP, the SDP and the RCP for communication to the central facility.

- Processing algorithms. These are basically beamforming, envelope forming and detection algorithms, all supplied by the central facility and received and deposited by the RCP.

2. Central Facility Files and Interface

The central facility file and interface system is as follows:

- SP, LP sensor waveforms. These have been requested by the ECP or in special cases, by the PUP. The ECP performs extended processing on these waveforms to enhance discrimination; the PUP may use them for research and development or for checking algorithms. The waveforms are received from the remote facility and deposited on the CSE by the CCP. The SCP checks off the waveform requests concerned and stores the waveforms routinely and permanently in the DB for further evaluation by the PUP.

- SP, LP requested beams. These waveforms have been requested by the DAP upon positive association of the detection data received for the focal parameters of the associated event. They are used by the ECP for refined association, initial discrimination, and event classification by source and region. The waveforms are received from the remote facility and deposited on the CSE by the CCP. The SCP checks off the waveform requests concerned and stores the waveforms routinely and for long term use in the DB. The waveforms may also have been requested by the DAP if this was desired for the association process.

- DAP waveform requests. These are issued upon positive association of the detection data received. They consist routinely of requests for beamed waveforms given the approximate focal parameters of the associated event. The requests are stored on the RSE and read by the CCP for transmission to the central facility, and by the SCP for system performance control. The DAP may also request special beamed waveforms to enhance the association process.

- DAP special information request. This is a general type information request made when the association process needs further information. The request may call for beamed envelopes for a certain time window and focal parameters, for lowering the detection threshold so that more detection bulletins are sent in, or merely for detection bulletins for certain beams, independent of the detection threshold in force at that moment. The requests are stored on the RSE and read by the CCP and the SCP as above.

- PUP special waveform requests. The PUP may request sensor or beam waveforms for research and development purposes or for checking out algorithms. Requests could be made, for instance, for certain regional events, events within a certain magnitude range, or events processed at a certain station. The requests are stored on the RSE and read by the CCP and the SCP as above.

- SP beam envelopes. These are sent in by the DCP at the request of the DAP to enhance the association process if so desired. The envelope waveforms are received and deposited by the CCP.

- SP long term noise. The mean and s.d. of maximum log A/T values measured from non-overlapping 15-sec beam envelopes where no signal is present are sent in for k beams. The DAP uses this information to estimate the station and network detection capabilities. The SCP uses this information for system quality control. These noise statistics are deposited in the DB by the SCP.

- Signal decay function. This function is determined and updated by the PUP based on received event signals. This function may vary by region and station. It is read from the CSE by the CCP for transmission to the remote facility for signal time window computation by the DCP.

- Detection thresholds. These are log A/T z-statistic threshold margins which an event signal envelope must exceed for detection. They are determined per region and per station by THE SCP based on desirable and feasible network detection capability, processing and communications queues, and the "cost" of false alarms and missed detections. The network capability is determined by station noise and detection thresholds. The detection thresholds are stored and updated on the RSE by the SCP for transmission to the remote facility by the CCP, and deposited in the DB by the SCP for system performance evaluation by the PUP.

- SDP detection bulletins. These are sent in from the stations whenever a beam envelope exceeds the detection threshold, and contain all data relevant for detection association by the DAP (see remote facility file and interface system description). The SCP keeps accounting statistics on all detection bulletins received and verifies their value against detection association reports as part of its quality control function. The detection bulletins are received and deposited by the CCP.

- Station and network detection capabilities. These are continuously estimated by the DAP from station noise, detection thresholds and magnitude bias. They are also evaluated by the PUP from actual event signal detections for comparison with estimates from noise. They are monitored by the SCP to adjust threshold levels if necessary, and deposited in the DB.

- Detection association report. This is issued upon positive association of detection data and contains:
  - Focal parameters and s.d.
  - Station detection levels
  - Report identification.

  They are used by the ECP for refined association by means of visual analysis and processing of beamed waveforms, and by the SCP for system quality control and deposit in the DB.

- Parameter anomaly corrections. These are compiled by the PUP from detection data received, for region-station pairs, and may concern:
  - Beam direction
  - $dT/d\Delta$
  - Sensor delay times
  - Magnitude (m_b and M_s)
  - Dominant period
  - Travel time
  - Spectral parameters.

  The corrections may be expressed as functions of the location coordinates with respect to a regional master event, and as a function of magnitude. Updates are provided by the PUP and stored on the CSE for transmission to the remote facility by the CCP, and for use by the DAP and the ECP.

- Event classification report. This is compiled by the ECP from beamed waveforms and possibly from requested sensor waveforms. It contains:
  - Event identification
  - Focal parameters
  - Regional classification (coordinates with respect to regional master events)
  - Source classification

- Discriminants
- Anomaly matrix.

It is used by the SCP for quality control and system check, and by system users for retrieval of data for parameter updating and for research and development.

- Queuing data. Processing and communications load information is sent to the SCP for system control. Queuing data from the remote facility are received and deposited on the CSE by the CCP. The central facility processors deposit their own status on the CSE.

- Processing algorithms. These are deposited by the PUP. These include:
  - Beamforming
  - Envelope forming
  - Detection
  - Detection capability estimation
  - Discriminants
  - Matched filter
  - Signal separation (cepstrum, f-k)
  - Spectral analysis
  - Association
  - Anomaly correction
  - Adaptive beamforming
  - Maximum entropy.

C. PARAMETER INTERACTION

This subsection combines the system block diagram, data flow, file and interface descriptions into the parameter interaction diagram shown in Figure II-4. The left-hand column contains the parameter file names, the right-hand seven columns describe the data-flow and parameter and processor interactions. The RSD, RSE, RCP, CCP and CSE have been omitted in his scheme.

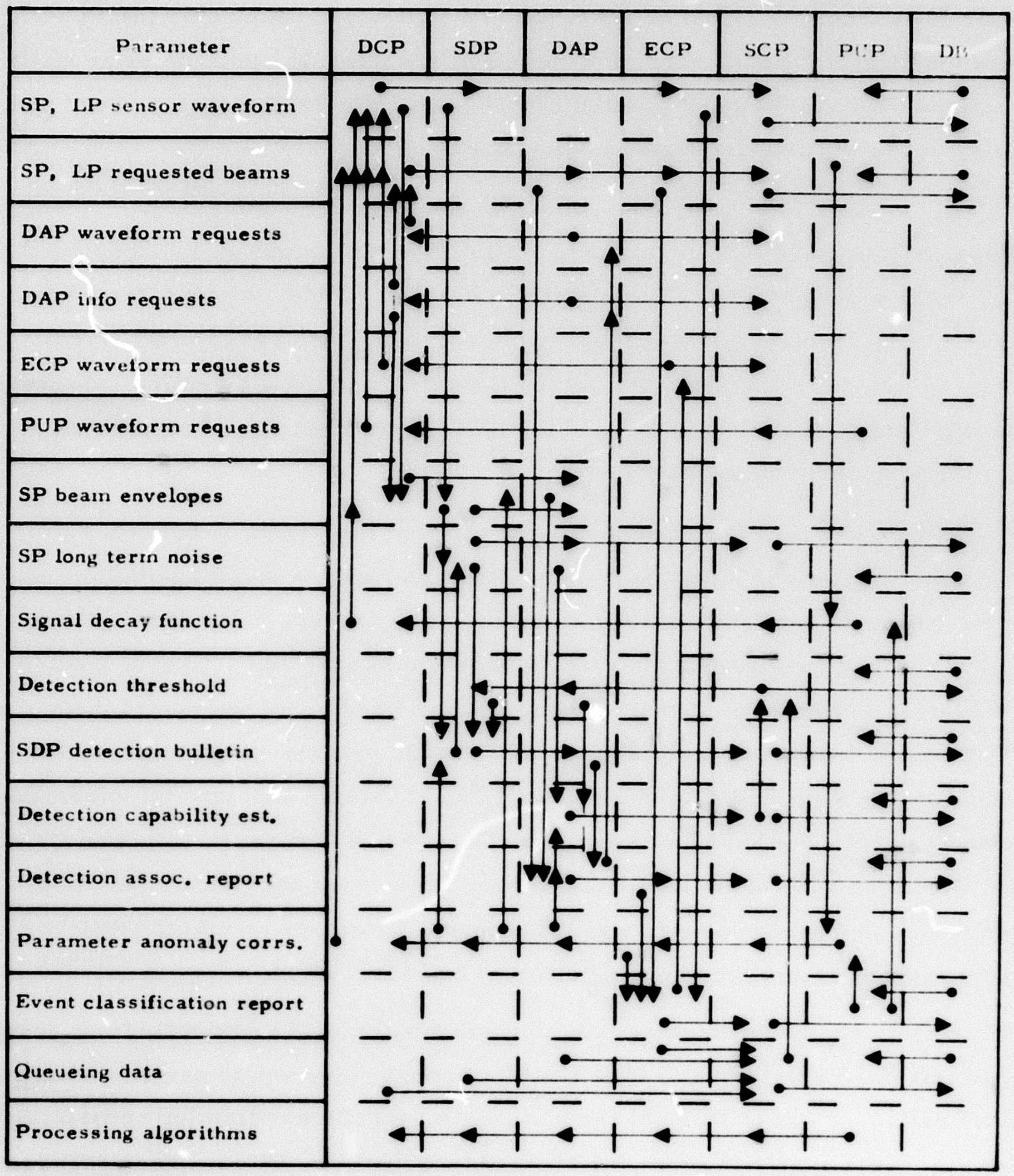


FIGURE II-4

PARAMETER INTERACTION DIAGRAM

The DCP collects the sensor waveforms and handles the DAP, ECP and PUP waveform and information requests for which it determines the time windows from the signal decay function supplied and updated by the PUP. In beamforming for specified focal parameters it applies the parameter anomaly corrections also supplied and updated by the PUP. The DCP may also form and send envelopes when so requested by the DAP.

The flow in the SDP column pertains to the beam envelope forming, envelope detection and long-term noise statistics updating processes described in the previous subsections. The maximum beam envelope, the long-term noise statistics, and the detection threshold value received from the central facility are input to the detection algorithm which activates sending a detection bulletin to the DAP when a signal is found. If no signal is detected the beam envelopes update the long-term noise statistics.

The DAP combines information from the detection bulletin received from the various stations, and the direction, $dT/d\Delta$ and magnitude anomaly statistics to optimize its event association process. Positive association yields a first estimate of the event focal parameters, and activates issuing of the association report and the DAP request for waveforms beamed at those focal parameters. In certain cases the association process may require extra information, to be provided by the remote facility via the DAP special information request. The DAP furthermore estimates the station and network detection capabilities for each region from station long-term noise statistics, detection thresholds, and magnitude statistics. These estimates are sent to the SCP for use in threshold control and general quality control.

The ECP uses the detection association data and the DAP requested beamed waveforms to further refine the focal parameters and to perform event discrimination and classification resulting in the event classification report. These processes require parameter anomaly corrections. If extended processing is desired the ECP requests the sensor waveforms from certain stations. The event classification report is sent to the SCP for quality control and deposit in the DB.

The SCP uses the numbers of waveform requests, detection bulletins, assocation reports, event classification reports and waveforms sent, and detection capabilities, signal decay functions and queuing data in its overall system quality control. Setting of the station detection threshold levels is based on the desired network detection capability, station noise, regional seismicity, queuing information, and false alarm versus missed detection cost considerations by the analyst. The SCP furthermore transfers all relevant data from the CSE to the DB.

The PUP, finally, occasionally issues waveform requests and retrieves the DB data to determine parameter updates and signal decay functions from the beamed waveforms, the beam parameters sent with these waveforms, and the event classification data. It furthermore uses DB data to update and check algorithms, to evaluate system and subsystem performance, and to perform research and development.

D. STORAGE AND COMMUNICATIONS REQUIREMENTS

Modifications or corrections to the parameters azimuth, inverse velocity, m_b, M_s, and the SP and LP sensor beamforming delay anomalies are the major items which have a strong impact on the need for additional system storage and communication capacity. For an earth model consisting of 100 seismic regions, and the 25 projected stations with 19 SP and 7 LP sensors each, the central facility storage requirements for these corrections are:

$$4 \times 25 \times 100 = 10{,}000 \text{ words}$$

for azimuth, inverse velocity, m_b, M_s corrections;

$$19 \times 25 \times 100 = 47,500 \text{ words}$$

for the SP sensor delay time corrections, and

$$7 \times 25 \times 100 = 17,500 \text{ words}$$

for the LP sensor delay time corrections. Unless the LP arrays are large, however, any LP beamforming delay anomalies can probably be ignored. This amounts to a total of 75,000 words extra CSE storage capacity for parameter update purposes. The RSE extra storage capacity for parameter updating is:

$$(4 + 19 + 7) \times 100 = 3,000 \text{ words.}$$

The communications load is increased, first by the beam and correction parameters used by the station and sent in together with the waveforms, and, second, by the feedback from the SCP to the station, of the parameter corrections compiled by the PUP. The first (forward) data flow takes place on-line, the feedback correction data may be sent off-line (e.g., on tape by mail), but preferably will be transmitted by the communications system since the load will not be very large. With a conservative station detection rate estimate of one event per hour, i.e., a station sends in requested beams on the average once an hour, the communications load due to parameter updating amounts to 2 + 19 + 7 = 28 words every hour for azimuth and inverse velocity corrections, and for SP and LP sensor delay times. With 16 bits per word and a bit rate of 50 baud the extra time required for sending this information with the requested waveforms is 9.6 seconds net.

SECTION III

PARAMETER UPDATE TECHNIQUES

In this section two aspects of parameter update and information feedback design are studied in more detail. The first subsection suggests approaches to the problem of compiling and applying corrections to parameters used in beamforming, detection association, and event classification. The second subsection studies the problems arising in the design of a threshold control that minimizes the total cost of decision errors made at the various system processing levels.

A. REGIONAL CORRECTIONS

1. General Considerations

Events occurring within certain seismic regions frequently show similar source characteristics causing similarity in signals and in signal processing parameters at the stations. The degree of this similarity depends on:

- The source characteristics (mechanism, radiation pattern, depth, magnitude)
- The propagation path between event epicenter and station
- Station site crustal characteristics.

This similarity makes it possible to compile statistics of signal and signal processing parameters for certain station-region combinations. Parameters concerned are, for instance, signal shape, spectral contents, deviations in azimuth from the great circle path, velocity deviations, magnitude bias, array sensor beamforming delay time anomalies, non-planar wavefronts, etc.

A priori knowledge of these parameter statistics will enhance the beamforming, detection, association, discrimination, and classification processes. The most logical place to compile these statistics is at the central facility where the best estimates of event focal parameters are obtained and where the relevant data from all stations are received and stored. The simultaneous compilation and application of parameter statistics is the essence of the parameter update problem.

2. Regional Correction Techniques

It is reasonable to use as much data as possible from other sources in the start-up procedure for a new array. The seismicity of the earth has been discussed at length, and a preliminary regionalization can be made on the basis of this data. If single site data is available for the location of the new array, preliminary estimates of travel-time and magnitude corrections can be made.

In the absence of any experience about the array location, the uncorrected data must be reported. When enough corrections have been calculated for a region, a function describing the variations in corrections over the region can be fitted to the data. Obviously this point will be reached at different times for different regions, because of the varying seismicity of the earth.

Some human judgment would be required at this point. An analyst can determine the boundary between two regions which are not clearly separated in terms of event density by taking geological data into account, or by systematic variations in the observed corrections.

It may also occur that corrections from a given region cluster around two or more different values at each point, as might occur if different source mechanisms were operating in that region. After enough data has been collected which indicates that multiple relations between the parameters and the source region have been found, one reasonable approach is to report different events, corresponding to the different sets of corrected observations, and let the detection association processor decide which one was the most plausible. A second approach is to allow a multiplicity in the values of certain variables in the detection bulletin and have the detection association processor perform an elementary level of classification during association.

An analyst might at this time notice that some other variable such as magnitude was influencing the corrections. In this case it should be included in the analysis, and in the treatment below it is assumed that this is the case.

In fitting a curve to a set of points the weight given each point must be taken into consideration. Ordinarily this weight is the same for all points, but in the present case a more realistic assumption can be made. It is shown by Clay (1972) that the variance of a single measurement of the azimuth, θ, by means of a square array of sensors, sampling at the Nyquist time and space interval is

$$\sigma_{\theta}^{2} = \left(\frac{6}{\rho}\right) \frac{1}{K^{3}\pi^{2}\sin^{2}\theta} \qquad \text{(III-1)}$$

and the apparent velocity

$$\sigma_{v}^{2} = v^{2}\left(\frac{6}{\rho}\right) \frac{1}{K^{3}\pi^{2}\cos^{2}\theta}, \qquad \text{(III-2)}$$

where K is the number of sensors and ρ is the signal-to-noise ratio. Weighting measurements according to the reciprocal of the variance of the measurement will thus favor those of high signal-to-noise ratio, which is a reasonable procedure.

Now we consider specific ways in which the curve fitting process might take place. Let x_i be an observed correction to the i-th variable (azimuth, velocity, arrival time, or magnitude). It is assumed that there is a functional relation between this correction and the observed azimuth, velocity, magnitude, and perhaps some other variable not obvious at this time. Variables such as depth almost certainly affect the corrections, but cannot be included in this analysis, because they cannot easily be determined at a single array. The functional form for the correction x_i to the i-th parameter (θ, $dT/d\Delta$,...) is

$$x_i = F_i\left(\theta, \frac{dT}{d\Delta}, M, \ldots\right) . \qquad \text{(III-3)}$$

The way this function is approximated will depend on the analyst's judgment.

One obvious approach, if the data shows an extremum, is to expand F_i as a Taylor series about the extremum.

$$x_i = X_i + \frac{\partial^2 F_i}{\partial \theta^2}(\theta - \hat{\theta})^2 + \frac{\partial^2 F_i}{\partial v^2}(v - \hat{v})^2 + \frac{\partial^2 F_i}{\partial M^2}(M - \hat{M})^2 + \ldots \qquad \text{(III-4)}$$

where X_i is a constant and terms of order higher than three have been ignored. The problem then is to find the partial second derivatives and the coordinates $\hat{\theta}$, $\hat{v}$ and $\hat{M}$ of the extremum of equation (III-4) by regression on the observations, taking into account the probable error of each observation by means of equations (III-1) and (III-2). This is a standard problem in curve fitting and will not be discussed further here.

Other functional forms may be more appropriate if the data does not show an extremum with one or more variables. For example, if the corrections vary rapidly with angle, we might assume the form

$$x_i = X_i + A(\theta^n - \hat{\theta}^n) + \frac{\partial^2 F_i}{\partial v^2}(v - \hat{v})^2 + \frac{\partial^2 F_i}{\partial M^2}(M - \hat{M})^2 + \ldots \qquad \text{(III-5)}$$

where the regression is on the exponent n and the parameter $\hat{\theta}$. Experience and the form of the data will suggest other possibilities.

As more data are collected they will be incorporated into the regression. It is not necessary to store all the data previously collected, once the functional form of x_i has been determined. To update coefficients in equation (III-4), prior estimates of the coefficient, the sum of the weights used in the prior estimate, and the weight of the new data are used to generate new values of the coefficients. Therefore, the coefficients can be continuously updated as new data comes in without extensive storage requirements.

A somewhat different problem is the updating of sensor delay times. For beamforming of signals with a reasonable signal-to-noise ratio, the sensor delay times can be found at the station directly, without applying corrections, from the cross correlations of sensor outputs. For each region, however, consistent deviations from plane-wave propagation may be used to enhance the beamforming of the weaker signals given the event location. The delay time corrections then must be classified by station and region, and a weighting process similar to the one described above may be applied to find the least-error corrections. If these corrections are established, updated and stored at the station, only the event location (or preferably, all of its focal parameters) needs to be communicated from the central facility. It may be convenient, however, to perform these processes at the central facility, in which case the delay time anomalies must be sent in from the stations.

Since corrections must be based on the observed values of the variables, rather than on calibration events, the best that can be hoped for is that the corrections found above be consistent. The values of the reported parameters can be corrected to the values ultimately assigned to the event, but those final values may not be correct. In the absence of a calibration event the error between the assigned and true value should approach a constant value (bias) for each region. For instance, according to Chiburis, (1972), the event locations determined at a number of stations from travel time corrected array measurements may show a relative difference of only a few kilometers while the true location error may be on the order of 50 kilometers. The update procedure can be invoked less often when the observations become consistent to some pre-determined degree. This point might be reached when the uncertainties of the focal parameters resulting from detection association or event classification cannot be decreased further or are within a pre-determined value.

B. THRESHOLD CONTROL

This subsection discusses the problems related to the design of a detection threshold control which minimizes the cost incurred by erroneous decisions at the various processing levels in the seismic surveillance system. The introductory part establishes the need for such control. The second part presents general aspects of threshold control design suggesting approaches both, at the stations and at the systems level. A minimum cost threshold control algorithm for decisions at the station level is developed in the third part. In part four, the interdependence of threshold control parameters is discussed. In part five it is indicated that further research on the subject of threshold control is essential to the overall system design; the specific areas for that research are listed.

1. Introduction

Given its external circumstances (e.g., noise, seismicity, network configuration), the performance of a seismic surveillance system depends critically on two factors:

- The precision of the models used to describe the event signal and noise processes
- The efficiency of selecting data to be transferred between processors.

The first factor determines the accuracy of the estimated signal, which effects directly the quality of signal detections by the station detection processor, the quality of detection association by the detection association processor, and the quality of event classification by the event classification processor. The relevance and the quality of data to be communicated from remote stations to the central facility are determined by the efficiency of detectors in selecting possible event data in preference to noise data. They are also influenced by the efficiency of the decision processes involved in detection associations and event classification because of the data requests resulting from these processes. The system performance can be evaluated by estimating the total cost incurred (i.e., the damage done) by the following types of decision errors:

- False alarm detections, erroneous detection associations and erroneous decisions to request further data
- The loss of desired event data due to missed signal detections at a station, missed detection associations and missed event classifications.

For a system with fixed processing, storage and communications capacities excessive false alarm rates at a station will generate an excessive amount of detection bulletins. These may cause the following problems, especially during earthquake swarms or other periods of high seismic activity:

- Excessive communication and processing loads resulting in communication and processing delays, and thereby in excessive storage loads
- Loss of event detections due to degradation of the detection association process because of excessive numbers of false alarm detection bulletins
- Loss of data when delays exceed the data holding period at the station.

Transmission of data in response to requests based on erroneous decisions in the detection association or event classification processes will result in the first and third type of problems described above. Because of the data density of requested waveforms, this type of decision error may cause even more severe communication problems than false alarms at the stations. The consequences of the various kinds of decision errors are summarized in Figure III-1.

The rate of false alarm detections may be reduced by setting an appropriate detection threshold for each beam at each station. Too high a threshold, however, may result in failure to send needed detection data to the central facility, which also degrades the detection association and event classification. At the central facility, one may desire to set decision thresholds for requesting data and for sending association reports, to reduce the

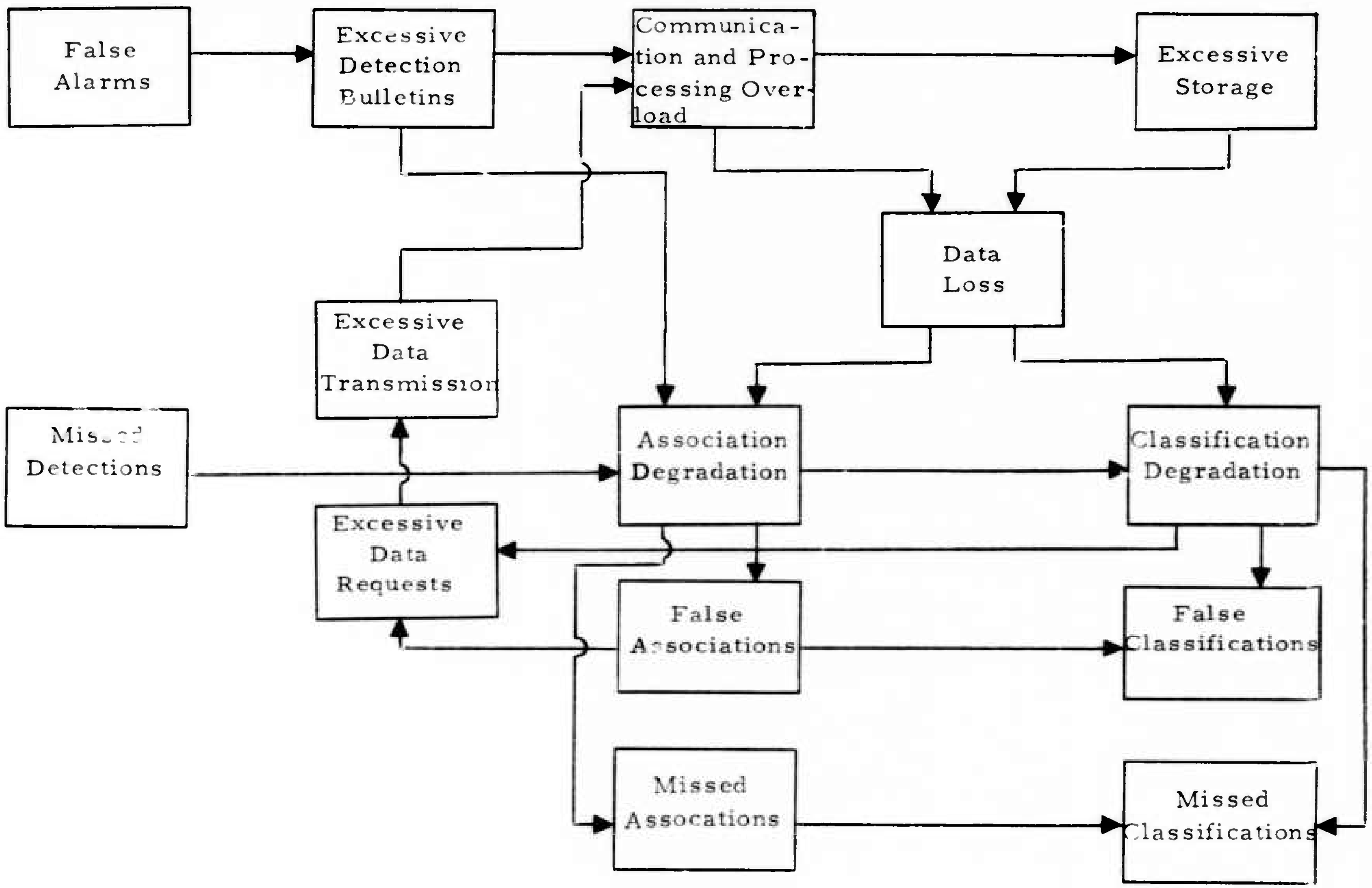


FIGURE III-1

DECISION ERROR CONSEQUENCES

rate of irrelevant data transmissions. Also in this case, too high a decision threshold will lead to missed event detections and missed event classifications.

Therefore, a form of threshold control is needed which minimizes the total cost incurred by decision errors at the various processing levels in the surveillance system. The following parts of this subsection discuss the problems concerning the design and implementation of such threshold control. Although the analysis refers to the decentralized system concept, most of the considerations apply equally well to the threshold control design for a centralized system.

2. General Aspects of Threshold Control Design

Batchelor and Sampson (1973) described a threshold control approach based on Bayes' risk model for the case of fading radar signals in additive Gaussian noise. In the next part of this subsection, their approach is extended to the problem of minimizing errors in detecting seismic signals. The resulting algorithm explicitly evaluates a cost resulting from erroneous decisions to transmit data and from missed opportunities to retrieve detections of seismic events. The strategy followed in deriving this algorithm is to determine thresholds for each beam at each station, which minimize the cost of such errors.

The algorithm is derived for a threshold control model describing the sending of detection bulletins from a station to the central facility as an open loop process, i.e., without consideration to information feedback, such as data requests sent by the central facility to the stations, or information feedback about the processing, communication and storage loads at the various processing levels in the system. In that case, the minimum cost threshold at a station is found by specifying two threshold control parameters:

- The minimum magnitude of events in the regions covered by a beam that one wishes to detect (the target magnitude)
- The number of false alarms which can be tolerated by the system to avoid missing an event of magnitude equal to or greater than the target magnitude.

For this open loop model the resulting threshold only minimizes the cost of errors for the chosen control parameter combination. Different choices will result in different minimum costs. However, the open loop model assumes the trade-off between false alarms and missed detections to be constant and independent of, for example:

- The increase in processing, storage and communications demands due to the increase in the number of detection bulletins and requested waveforms
- Possible association degradation due to an increase in the number of false alarms
- Magnitude. For instance, one may desire to penalize or eliminate the detection of irrelevant, local low-magnitude events.

The threshold control model for a closed loop surveillance system, therefore, can be made more realistic, but is also considerably more complicated. It can be approximated, however, by modifying the open loop model. This is done by making the false alarm costs dependent on the amount of data communicated by increasing the cost greatly as the bulletin traffic approaches a certain designated channel capacity. Also, the cost equation can be augmented to include the cost of assocation and classification errors. This cost can similarly be made dependent on the amount of waveform data communicated as this amount, influenced by such errors, approaches the remaining channel capacity.

The closed loop threshold control model is expected to be self-regulating, i.e., the model will automatically find a unique set of threshold control parameters which minimize the total cost incurred by decision errors at the various processing levels in the system. This means that, for instance, the target magnitudes for each region are determined by the system rather than by the analyst. The system should be designed, however, to permit intervention by the analyst in case a change in target magnitude is desired for a certain seismic region. Such externally forced target magnitudes then will change the decision error cost. Alternatively, the target magnitude values may be changed by means of a re-assessment by the analyst of the trade-off between false alarm and missed detection costs. Furthermore, because of the dependence on the amount of data communicated, the minimum-cost threshold control parameters will change with variations in seismicity, for instance, in the case of earthquake swarms. Changing noise statistics, for instance, due to storms, seasonal changes, etc., will cause additional threshold control parameter variations.

An open loop threshold control algorithm which minimizes decision errors at the station level can be derived in a straight forward manner. This derivation is presented below. The closed loop threshold control minimizing the total decision error cost for the entire network requires separate and more extensive studies, preferably guided by system simulation reflecting the above-mentioned model approximations.

3. Open Loop Minimum Cost Threshold Control

Thresholds are applied to a set of beams at each station to detect possible events in the seismic regions covered by each beam. To minimize the cost of decision errors at a station, these thresholds may be determined as follows:

For a given station beam, let (see Figure III-2)

x be the detector output

$p_N(x)$ be the probability density function of the detector output given that only noise is present at the detector input

$p_S(x)$ be the probability density function of the detector output given that a signal from an event of target magnitude is present at the detector input.

The detector output is, in general, some linear estimate of the value log A/T. The measurement A is the maximum amplitude in a given time gate of the seismogram, and T is the period at the maximum amplitude. For noise as well as for signal, this value is, in general, normally distributed and the probability density functions may, therefore, be assumed to be:

$$p_N(x) = \frac{1}{\sqrt{2\pi}\sigma_N} \exp\left[-\frac{(x-\mu_N)^2}{2\sigma_N^2}\right] \quad \text{(III-6)}$$

and

$$p_S(x) = \frac{1}{\sqrt{2\pi}\sigma_S} \exp\left[-\frac{(x-\mu_S)^2}{2\sigma_S^2}\right] \quad \text{(III-7)}$$

where

μ_N is the mean value of the detector output given noise

σ_N is the standard deviation of the detector output given noise

μ_S is the mean value of the detector output given signal

σ_S is the standard deviation of the detector output given signal.

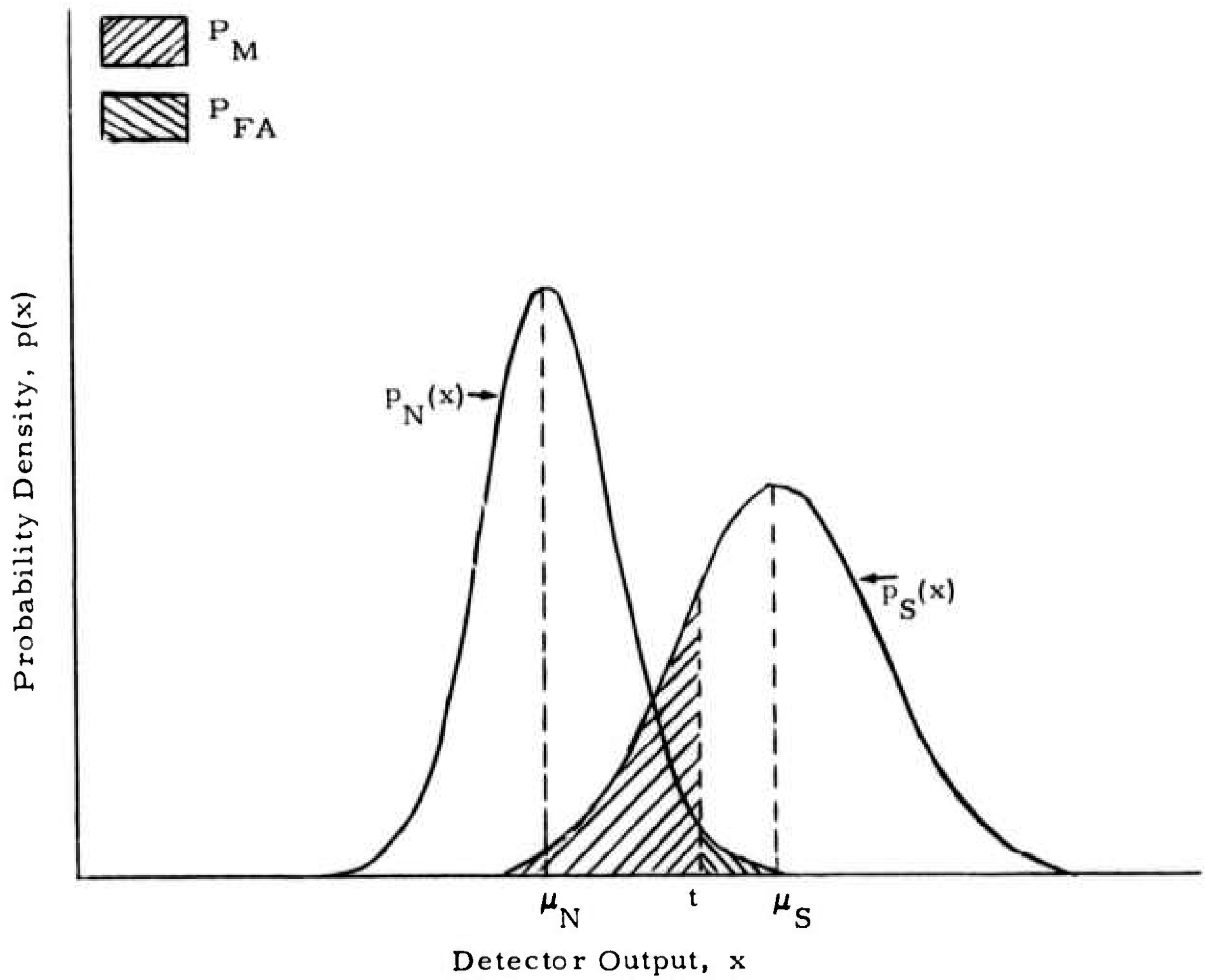


FIGURE III-2

DETECTION THRESHOLD SETTING

Let

t	be the threshold for detecting target magnitude event signals
$P_{FA}(t)$	be the probability of a false alarm given noise
$P_M(t)$	be the probability of missing a signal (i.e., the signal is below the threshold) given a target magnitude event signal
$P_D(t)$	be the probability of detecting a signal given a target magnitude event signal.

Then

$$P_{FA}(t) = 1 - \int_{-\infty}^{t} p_N(x)\, dx \quad , \tag{III-8}$$

and

$$P_M(t) = 1 - P_D = \int_{-\infty}^{t} p_S(x)\, dx \quad . \tag{III-9}$$

Let furthermore

C_T	be the total decision error cost per target magnitude event for the given beam
C_{FA}	be the error cost for transmitting the information resulting from a false alarm
C_M	be the error cost for a missed target magnitude event signal detection
D	be the expected number of detection trials (e.g., the expected number of independent measurements of maximum noise amplitude) between signals of events with a magnitude equal to or greater than the target magnitude.

Then

$$C = DC_{FA} P_{FA}(t) + C_M P_M(t). \qquad \text{(III-10)}$$

The threshold, t_o, minimizing the above total cost is determined by

$$\left(\frac{dC_T}{dt}\right)_{t = t_o} = -DC_{FA} P_N(t_o) + C_M P_N(t_o) = 0 \qquad \text{(III-11)}$$

or

$$\frac{p_S(t_o)}{p_N(t_o)} = \frac{DC_{FA}}{C_M} . \qquad \text{(III-12)}$$

The minimum-cost equation then is completely described by the likelihood of detection, K, defined by:

$$K = \ln \frac{p_S(t_o)}{p_N(t_o)} = \ln \frac{DC_{FA}}{C_M} . \qquad \text{(III-13)}$$

The likelihood of detection thus may be used as a lumped design parameter dependent on D and on the ratio C_{FA}/C_M. Since the cost ratio rather than the explicit costs of false alarms and missed detections are involved, C_{FA} may be set equal to one, and C_M equal to the number of false alarms, N_{FA}, tolerated to avoid missing the signal of a target magnitude event, so that

$$C_M / C_{FA} = N_{FA}. \qquad \text{(III-14)}$$

On this basis, C_T is the total cost of decision errors per missed event.

The parameter D can be further analyzed as follows. Let

E	be the seismicity of events of target magnitude or larger, for regions covered by the given beam, expressed in events per second
a and b	be the seismicity constants for the regions covered by the beam
m_o	be the target magnitude for events in the regions covered by the beam
p	be the a priori probability that the detector output for the given beam is greater than that of any other beam given noise
τ_N	be the time (in seconds) between independent detector trials given noise (i.e., τ_N is the time gate of detector input data yielding a detector output.)

Then

$$E = e^{a - bm_o} \tag{III-15}$$

and the expected number of seconds between signals from target magnitude events or larger events is $1/E$. The expected number of detector trials between signals from target magnitude events or larger events then is

$$D = p/E\,\tau_N \,. \tag{III-16}$$

For the case where at the station the world is covered by J beams, and the noise peaks occur equally likely on any beam (isotropic noise)

$$p = 1/J \tag{III-17}$$

and

$$D = 1/JE\,\tau_N \tag{III-18}$$

or

$$D = \alpha\, e^{\beta m_c} \tag{III-19}$$

where

$$\alpha = \frac{e^{-a}}{J\,\tau_N} \tag{III-20}$$

and

$$\beta = b. \tag{III-21}$$

D obviously varies from beam to beam, dependent on the seismicity of the regions covered by a beam, and dependent on the target magnitude set for those regions. It may further vary with the beams if the noise is not isotropic. The number of independent detection trials increases exponentially with the target magnitude.

The combination of equations (III-13), (III-14) and (III-19) leads to:

$$K = \beta m_o + \ln\alpha - \ln N_{FA} \;. \tag{III-22}$$

To find the minimum cost threshold, the minimum cost equation (III-13) must be solved by substituting the probability density functions given by equations (III-6) and (III-7), which results in an expression for a quadratic detector:

$$\frac{(t_o - \mu_N)^2}{2\sigma_N^2} - \frac{(t_o - \mu_S)^2}{2\sigma_S^2} = K - \ln\frac{\sigma_N}{\sigma_S} \;. \tag{III-23}$$

The complexity of the solutions for this equation can be bypassed, without losing the character of threshold evaluation, by considering the linear detector case where $\sigma_N = \sigma_S = \sigma$. For this case the equation becomes linear in t_o and the minimum cost threshold is given by

$$t_o = \frac{\mu_S + \mu_N}{2} + \frac{K\sigma^2}{\mu_S - \mu_N} . \qquad \text{(III-24)}$$

For the linear detector, evidently, the threshold is set at some K-dependent value above the average value of the mean detector outputs for noise and target magnitude event signal, respectively. This average value occurs at the intersection of the two probability density functions. This is illustrated in Figure III-3. For low target magnitudes, due to their relatively high seismicity, the number of trials between target magnitude event signals is low and K may become negative. In that case, $p_S(t_o)$ is less than $p_N(t_o)$, and evidently the minimum-cost threshold is then set at a value lower than at the intersection of $p_S(x)$ and $p_N(x)$. Furthermore, if for given target magnitude and seismicity, the cost of a missed detection relative to the cost of false alarms is raised, then the likelihood of detection decreases and the threshold is moved to the left.

In seismic detection, in general, σ_S is greater than σ_N, and to find a truly minimum-cost threshold the solutions of equation (III-23) must be evaluated explicitly.

4. Interdependence of Critical Threshold Control Parameters

For the log A/T z-statistic detector suggested in Section II, $\mu_n = 0$ and $\sigma_N = 1$, which reduces equation (III-24) to:

$$t_o = \frac{\mu_S}{2} + \frac{K}{\mu_S} . \qquad \text{(III-25)}$$

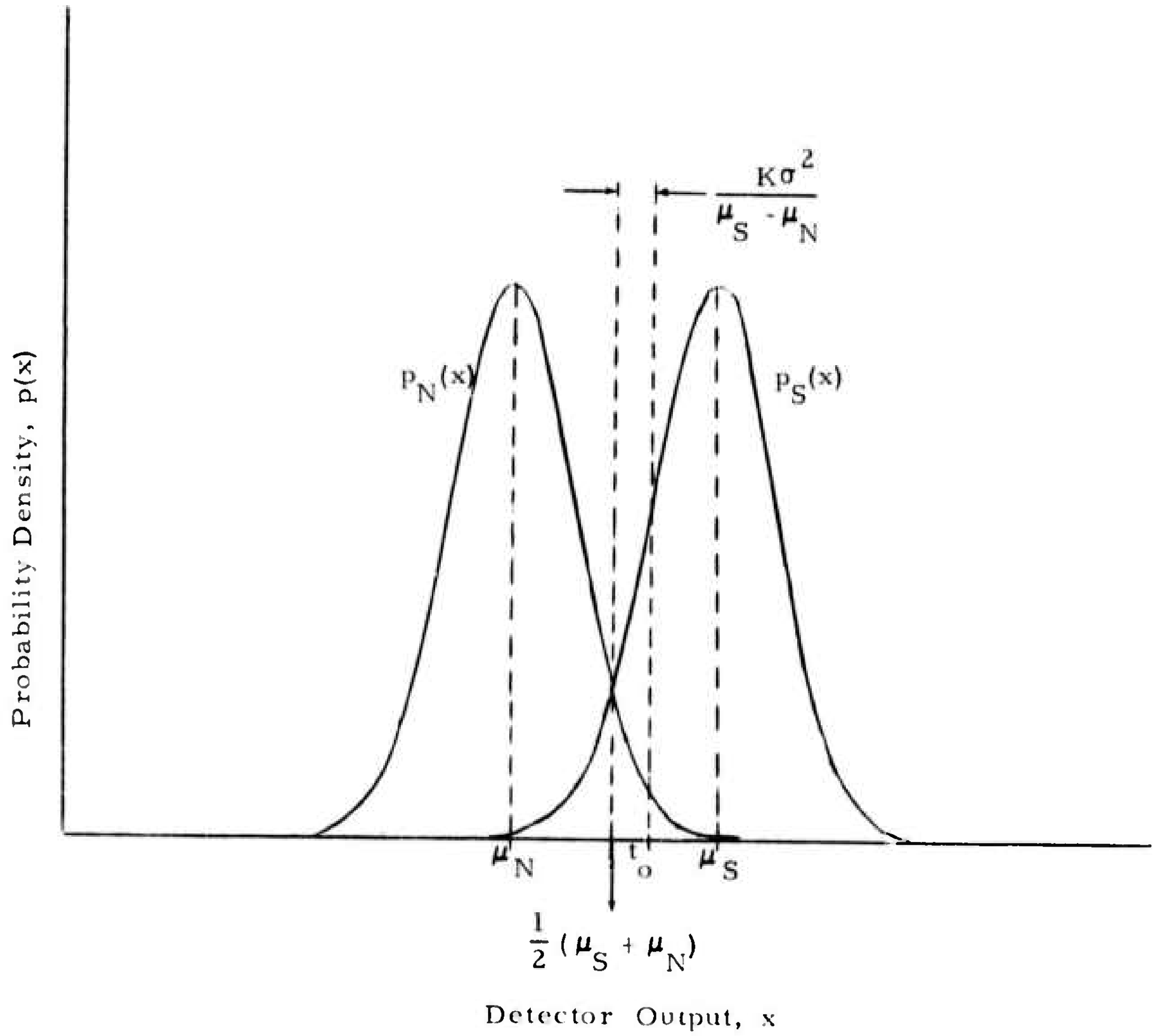


FIGURE III-3

MINIMUM-COST THRESHOLD SETTING
FOR A LINEAR DETECTOR

Since μ_S represents m_o (via the B-factor and the detector response), this shows that the minimum-cost threshold is controlled by the parameters K and m_o, or, because of equation (III-22), by m_o and N_{FA}. Inversely, one may say that m_o is determined by t_o and K, by N_{FA} and K, or by t_o and N_{FA}. A similar reasoning may be held for N_{FA} and for K.

For different detectors, a similar result is obtained via the transformations

$$d_S = \frac{\mu_S - \mu_N}{\sigma} \qquad \text{(III-26)}$$

and

$$d_o = \frac{t_o - \mu_N}{\sigma} \qquad \text{(III-27)}$$

where d_S and d_o can be called the normalized detector outputs for target magnitude event signals and threshold signals, respectively. This leads to

$$d_o = \frac{d_S}{2} + \frac{K}{d_S}, \qquad \text{(III-28)}$$

which similarly shows the interdependence between t_o (represented by d_o), m_o (represented by d_S), N_{FA} and K.

The minimum decision error cost per event may now be calculated, using equation (III-10) and substituting, as discussed previously,

$$C_M = N_{FA} \qquad \text{(III-29)}$$

and

$$C_{FA} = 1 \qquad \text{(III-30)}$$

to obtain

$$C_{T_{min}}(m_o, N_{FA}) = D(m_o)\, P_{FA}(m_o, N_{FA}) + N_{FA} P_M(m_o, N_{FA})\,. \qquad \text{(III-31)}$$

Thus, the minimum cost per event is determined by m_o and N_{FA}, or following the reasoning for the t_o dependence, by any two parameters selected from m_o, N_{FA}, K, t_o.

The interdependence of the critical threshold control parameters, sketched above, is summarized in Table III-1. This table also shows the interdependence if one of the parameters K, t_o, m_o or N_{FA} is held constant.

For instance, for a given K-value, the relationship between m_o and N_{FA} is described by equation (III-22). For an average beam seismicity (e.g., distributing the world seismicity equally over the number of beams at a station) it can be shown that approximately

$$N_{FA} = 10^{m_o - 1.2 - 0.43 K} \quad . \qquad \text{(III-32)}$$

This relationship is sketched for various, fixed values of K in Figure III-4. For instance, for K = 0 and m_o = 4.2, one could trade 1,000 false alarms for one missed detection.

As another example, equations (III-25) or (III-28) show the behavior of t_o as a function of m_o for any given K-value. In Figure III-5 using equation (III-25), t_o (the z-statistic detector threshold) is plotted as a function of μ_S (the z-statistic detector output for target magnitude event signals) for various, fixed values of K. The function has a minimum when

$$t_o = \mu_S = \sqrt{2K}, \quad K \geq 0. \qquad \text{(III-33)}$$

For $\mu_S < \sqrt{2K}$ the lower target magnitudes require a rapidly increasing minimum-cost threshold to avoid excessive false alarm costs. For $\mu_S > \sqrt{2K}$, the higher target magnitudes make signal detections

TABLE III-1

INTERDEPENDENCE OF CRITICAL THRESHOLD CONTROL PARAMETERS

$$t_o = \frac{\mu_S(m_o)}{2} + \frac{K}{\mu_S(m_o)} \quad ; \quad K = \ln D(m_o) - \ln N_{FA} \; ;$$

$$C_{T_{min}} = D(m_o)\, P_{FA}(m_o, N_{FA}) + N_{FA}\, P_M(m_o, N_{FA})$$

Given ↓	K	t_o	m_o	N_{FA}	C_T
	are determined by ... or ... or...				
-	m_o, N_{FA} m_o, t_o N_{FA}, t_o	m_o, K N_{FA}, K m_o, N_{FA}	K, N_{FA} K, t_o t_o, N_{FA}	K, m_o K, t_o t_o, m_o	K, t_o m_o, N_{FA} m_o, K N_{FA}, K m_o, t_o N_{FA}, t_o
K	-	m_o N_{FA}	N_{FA} t_o	m_o t_o	t_o m_o N_{FA}
t_o	m_o N_{FA}	-	K N_{FA}	K m_o	K m_o N_{FA}
m_o	t_o N_{FA}	K N_{FA}	-	K t_o	K t_o N_{FA}
N_{FA}	t_o m_o	K m_o	K t_o	-	K t_o m_o

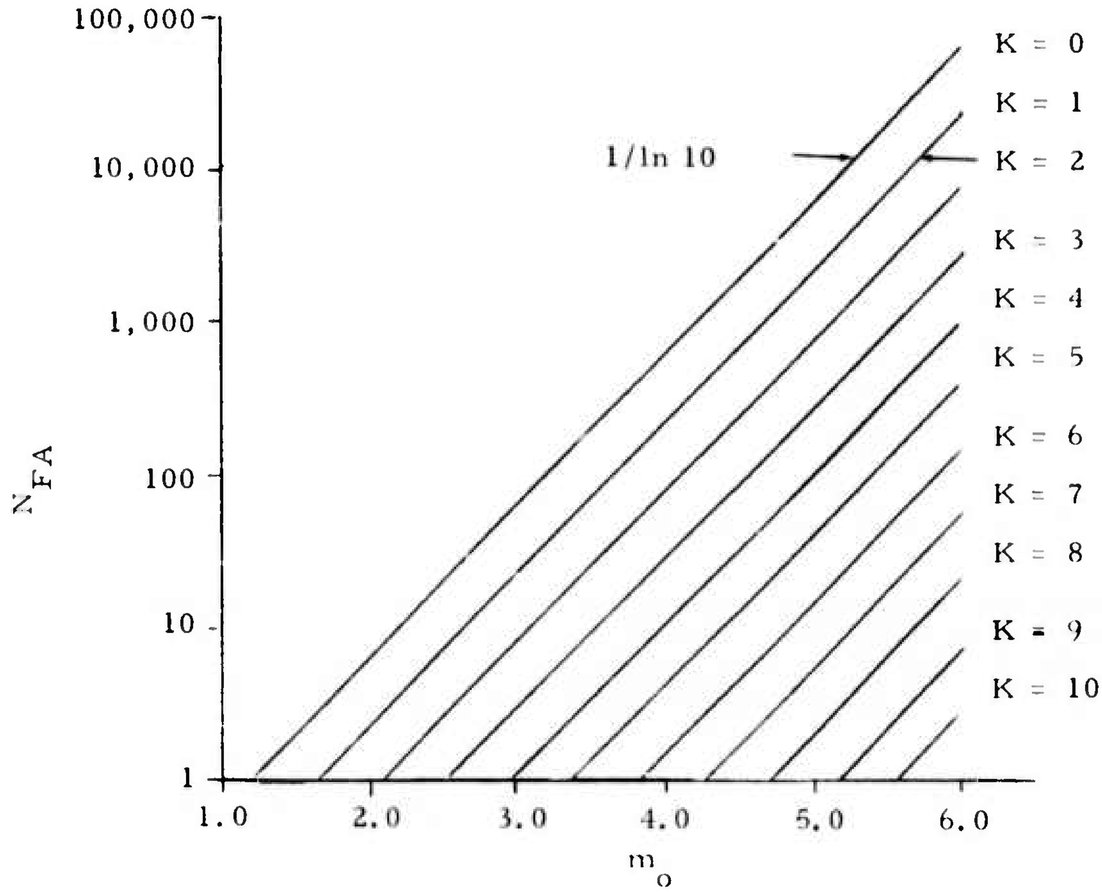


FIGURE III-4

MISSED-DETECTION-OVER-FALSE-ALARM COST RATIO
AS A FUNCTION OF TARGET MAGNITUDE FOR
A GIVEN LIKELIHOOD OF DETECTION
(FOR AVERAGE SEISMICITY BEAMS)

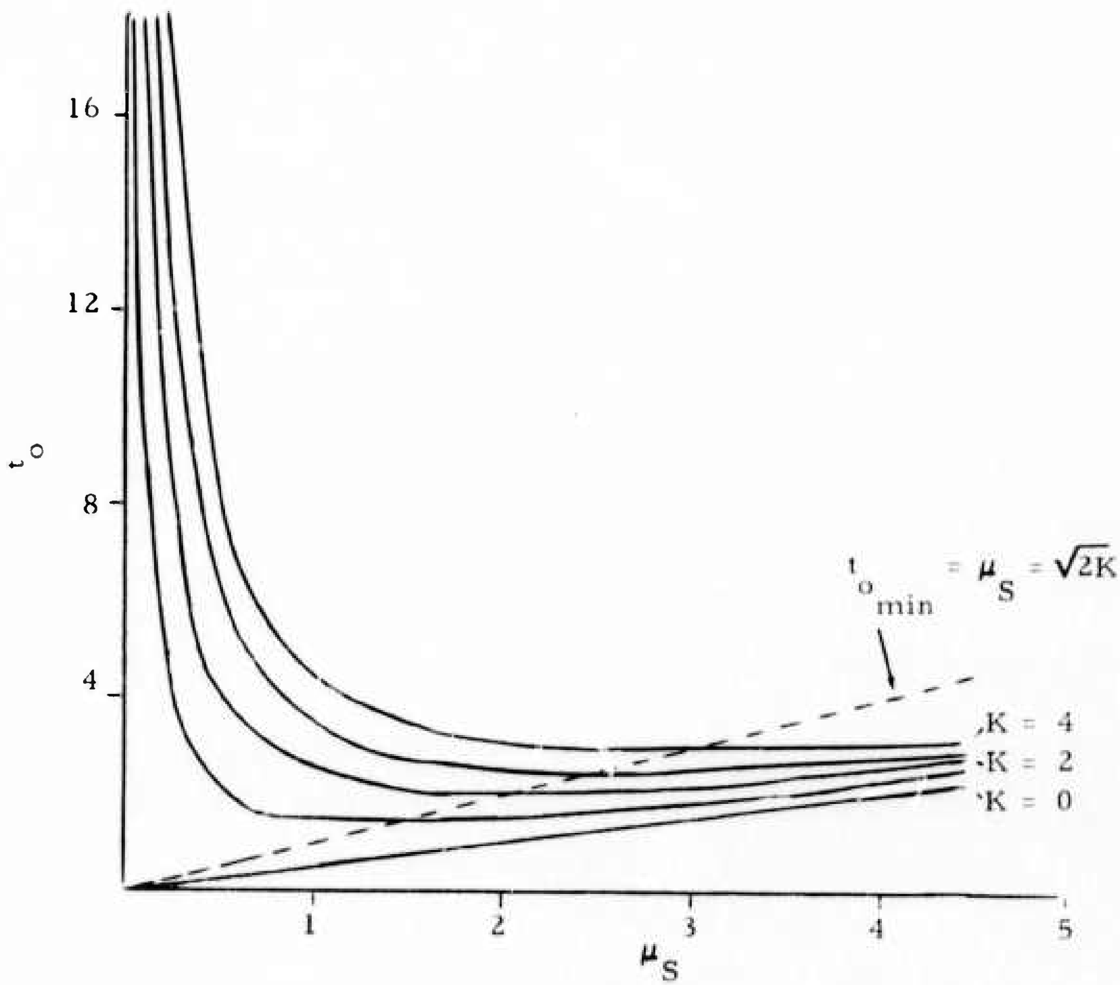


FIGURE III-5

MINIMUM-COST THRESHOLD VERSUS TARGET MAGNITUDE EVENT SIGNAL DETECTOR OUTPUT FOR A GIVEN LIKELIHOOD OF DETECTION increasingly more likely. This reduces the probability of false alarms for the specified likelihood of detection, and the minimum-cost threshold needs to be raised only slowly when increasing the target magnitude. Operating at the minimum threshold for a specified value of K means that a maximum number of events will be detected for this specified likelihood of detection.

Various strategies may be followed in the design of a minimum-cost threshold control. In each strategy in general a pair of parameters are selected from K, m_o, N_{FA} and t_o; different strategies may result in different minimum costs. One plausible strategy, for instance, is to first select a target magnitude. Based on analytic studies and system simulation, one may then choose a reasonable value of N_{FA} reflecting the trade-off between missed detections and false alarms. For a given region with a known seismicity one can plot the N_{FA}-versus-m_o curves for fixed K-values, as presented in Figure III-4. The choice of m_o and N_{FA} then determines K. Next, the value of μ_S is determined from m_o, the B-factor for the given region, and the detector response. For the z-statistic detector, this response is given by the mean and standard deviation of the log A/T values for noise. Using the curves of Figure III-5, the threshold then follows from the K- and μ_S-values determined above. Finally, the cost minima may be plotted as a function of parameter selections, corresponding to equation (III-31).

Another strategy is to follow the constraint that a maximum number of events be detected for a given likelihood of detection. This results in the minimum threshold control for given K, described by equation (III-33). In this strategy the entire control evidently is determined by the choice of only one of the parameters K, m_o, N_{FA} or t_o, and the cost minima can be determined as a function of that sole parameter. Since $t_o = \mu_S$, the probability of detection is 50 percent, and expressing the cost minima as a function of K, for instance, it can be shown that

$$C_{T_{min}}(K) = C_1 \, e^{C_2\sqrt{2K} - K}\left[e^{K} P_{FA}(\sqrt{2K}) + 0.5\right] \qquad \text{(III-34)}$$

where C_1 and C_2 are constants determined by the beam noise statistics and by the region's seismicity and B-factor. Substituting $\mu_S = \sqrt{2K}$ and $K = \mu_S{}^2/2$ in equation (III-34), the cost minima can be expressed as a function of μ_S for this strategy:

$$C_{T_{min}}(\mu_S) = C_1 \, e^{C_2 \mu_S - \frac{\mu_S^2}{2}}\left[e^{\frac{\mu_S^2}{2}} P_{FA}(\mu_S) + 0.5\right] \cdot \qquad \text{(III-35)}$$

The general shape of these minimum-cost functions is presented in Figure III-6, for a typical beam noise situation. The function shows a small maximum near $K = 0.05$ but drops rapidly with increasing K-and μ_S-values. Evidently, in this strategy and for this decision error cost model, the target magnitude should be set high in order to minimize decision error costs.

While in this latter strategy the entire threshold control is determined by the choice of a single parameter, one has no longer the freedom to choose the other parameters. In that case, the resulting N_{FA} value, for example, may turn out to be a non-realistic cost evaluation factor.

One may similarly study other strategies and compare the resulting minimum-cost functions to arrive at an optimum threshold control. The results are a direct consequence, however, of the decision error cost model chosen, in this case, equation (III-10). It is emphasized that this model applies only to the open loop decision problem at the station level, which does not take into account, for instance, the cost of overloading the processing, storage or communications capacities, or any other factors which may affect the assessment of decision error costs.

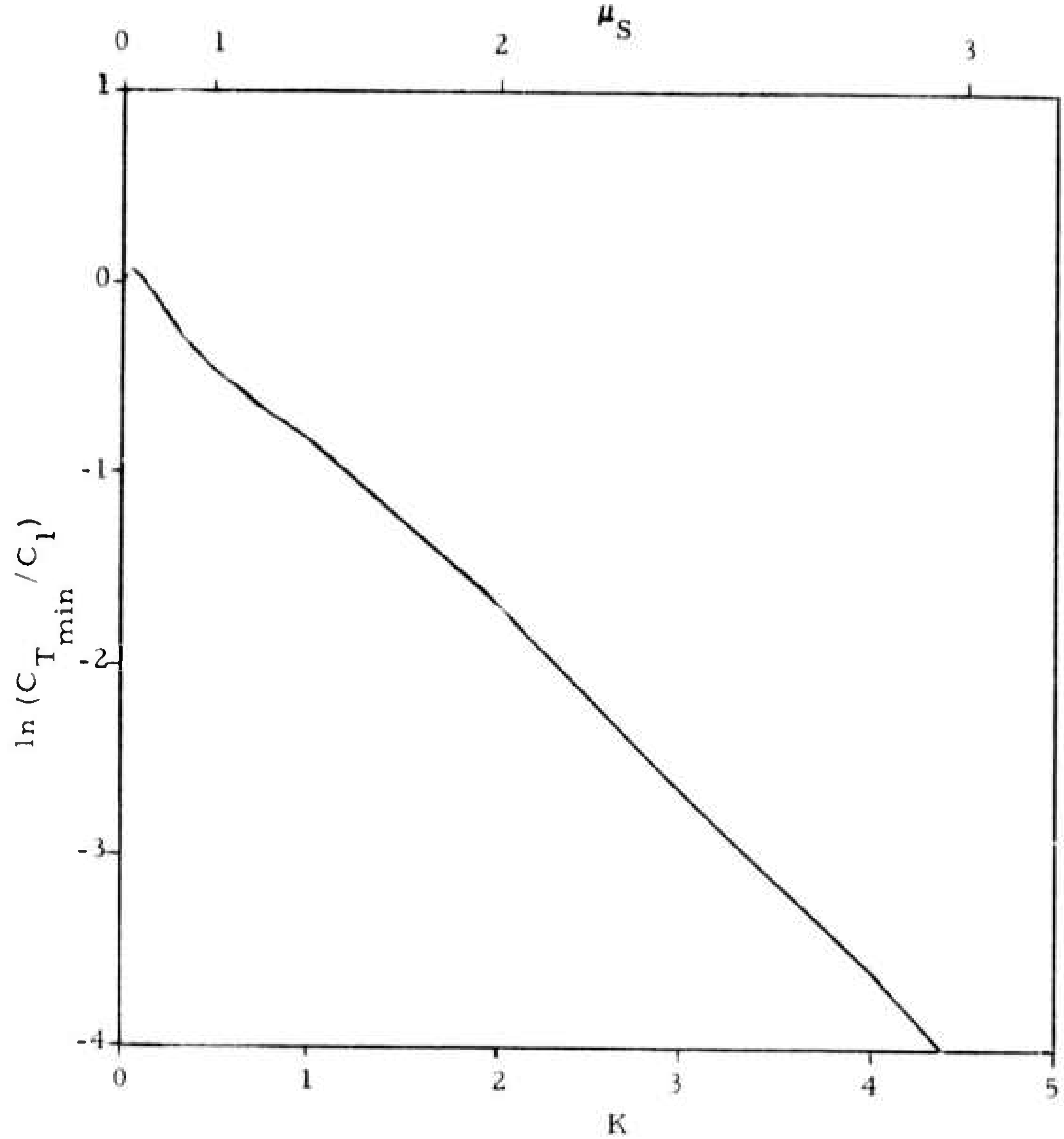


FIGURE III-6

TYPICAL CURVE OF COST MINIMA AS A FUNCTION OF K AND μ_S FOR STRATEGY OF MINIMUM THRESHOLD FOR GIVEN K

5. Final Remarks

The analysis presented above suggests that an exact knowledge and evaluation of all threshold control parameter relationships would strongly enhance the design of a minimum-cost threshold control. However, the minimization of decision error costs may be limited by a less than adequate overall system design. Critical in this respect are, for instance, the choice of station locations; the processing, storage and communications capacities; the type of association process. Therefore, the threshold control should take a central place in the overall system design.

For this reason it is recommended that a separate, detailed study be dedicated to the subject of threshold control. Such study should include the treatment of the closed loop problems mentioned before, a further analysis of decision error cost assessments, and the evaluation of all threshold control parameter relationships. System simulation, in particular of the detection association process, would strongly enhance this analysis.

SECTION IV
SUMMARY AND CONCLUSIONS

Aspects of parameter update and information feedback for a worldwide seismic surveillance network system have been presented as an extension of the preliminary seismic surveillance system study (Sax et al., 1974). In our work the basic system concepts developed in the preliminary study have been adopted and were extended to schematically include the compilation and application of parameter corrections for station-region combinations, decision threshold control, and the overall system quality and efficiency control. Since the accuracy of wave propagation and event classification parameters and the efficiency and relevance of transmitted data are essential to good system performance, the parameter update technique and the decision threshold control were studied in more detail.

The threshold control, which determines the network detection capability and the false alarm and missed detection rates, should be optimized and exercised at the highest system level, i.e., by the system control processor. A minimum decision error cost threshold control algorithm for decisions at a station was developed in an open loop concept, i.e., without consideration to information feedback. For that case, the minimum-cost threshold is determined by the so-called target magnitude (the minimum magnitude of events one desires to detect), and by the relative cost of false alarms and missed detections. For the closed loop model, however, the cost of saturating the processing, storage, and communications capacities, and the cost of decision errors involved in detection association, event classification and the sending of waveform requests must be taken into account.

Parameter update compilation and general research and development are conceived to be performed by a special parameter update processor from data deposited in the system's data bank. This processor may also interact with other control facility processors, in particular with the system control processor, to assist in special problems and evaluations. Parameter update algorithm approaches were suggested which predict anomolous wave propagation effects. Parameter updating is estimated to require approximately ten seconds of extra communication per hour, and 75,000 words of additional storage capacity at the central facility and 3,000 words at each station.

The emphasis in this study has been on sketching the scope of problems encountered in seismic network feedback and parameter update design. A good understanding of these problems is essential to the overall system design, in particular, with respect to system capacity, the detection association procedure, and the network configuration. Therefore, more refined studies are needed to focus on specific problems. These problem areas are:

- Threshold control optimization at all processing levels in the system
- Parameter update optimization (e.g., the problem of regionalization with emphasis on the trade-off between system warm-up time and seismic region size; the development of parameter update algorithms)

- Treatment of the detection problem for various types of non-stationary noise (storms, etc.)
- System quality and efficiency control.

SECTION V

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